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Journal of the
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

IRRIGATION WATER REQUIREMENTS OF LAWNS[a]

Discussion by Marvin E. Jensen

MARVIN E. JENSEN,[10] M. ASCE.—Engineers must estimate consumptive use although, in many cases, only limited supporting data are available. T. Quackenbush and J. T. Phelan have presented a method for estimating water requirements of lawns based on a modified Blaney-Criddle formula. They have stated that the irrigation water requirements can be computed using the modified formula and that they believe that reasonable estimates can be made for lawn grasses. However, no tangible evidence was presented that confirms or supports these statements. The modern practicing engineer is aware that estimating procedures do not yield precise answers. The engineer must know the confidence limits to be expected of an estimating procedure, i.e., will the calculated monthly consumptive use values be within ± 10% or ± 15% of the actual consumptive use most of the time? A comparison between calculated consumptive use using the proposed procedure and accurate lysimeter data not used in the original development of the empirical procedure would provide this information. At the least, a comparison between calculated values using the proposed procedure and the original data from which the procedure was derived would indicate its reliability.

The Blaney-Criddle formula was originally proposed for estimating seasonal consumptive use at a time when limited theoretical developments and experimental data were available. Seasonal estimates of consumptive use within approximately ± 10% of measured values probably can be expected when the Blaney-Criddle procedure is used in climatic regions similar to those under which the coefficients were determined. More reliable seasonal estimates are possible if the seasonal K-values are derived from local data, or if the formula is "calibrated" under local conditions.

Numerous proposals have been made for adapting the Blaney-Criddle formula for shorter periods of time. When used for a given year and at a given location, mean air temperature is the only climatic variable in the Blaney-Criddle formula. Extensive research data published since 1950 have vividly and conclusively shown that consumptive use for short periods of time is not as closely correlated with mean air temperature as it is with the net radiant energy received by the crop. One example of such data is presented by W. L. Pelton, K. M. King, and C. B. Tanner.[11] Net radiation closely controls the

[a] June, 1965, by Tyler H. Quackenbush and John T. Phelan (Proc. Paper 4350).

[10] Research Investigations Leader, Water Mgt. Northwest Branch, Soil and Water Conservation Research Div., Agric. Research Service, U. S. Dept. of Agric., Kimberly (Twin Falls), Idaho.

[11] Pelton, W. L., King, K. H., and Tanner, C. B., "An Evaluation of the Thornwaite and Mean Temperature Methods for Determining Potential Evapotranspiration," Agronomy Journal, Vol. 52, Madison, Wis., 1960, pp. 387-395.

evaporation or evapotranspiration rate even for 10-min intervals as has been demonstrated by C. H. M. Van Bavel, et. al.[12] and W. O. Pruitt.[13] Also, research data have clearly shown that consumptive use is not as accurately predicted with a modified Blaney-Criddle formula as it is with other empirical formulas using radiation as the major climatic variable, as shown in the work of Stevens and Stewart.[14]

The reluctance of engineers in the United States to use radiation energy for estimating consumptive use has a long history. L. J. Briggs and H. L. Shantz[15,16] clearly illustrated in 1916 that solar radiation controlled transpiration and that it was the primary causative factor. R. L. Lowry, Jr., and A. F. Johnson[17] recognized in 1942 that solar radiation would be a more reliable parameter to use in estimating consumptive use, but felt that inadequate radiation data were available at that time to permit its use. Empirical procedures using solar or net radiation are currently (1966) being used by engineers in countries where radiation data are extremely limited as compared to the United States. Examples of these methods are presented by H. Oliver[18] and L. Turc.[19] Penman-type equations that consider solar radiation, dew point temperature, mean air temperature, and windspeed are also being used extensively in countries where radiation data are considerably more limited that in the United States. Some states, such as Texas, have used a climatic index that includes solar radiation for extensive estimates of consumptive use for all crops on a statewide basis, as shown by C. B. Thompson.[20]

The modifications of the Blaney-Criddle formula proposed by Quackenbush and Phelan are similar to several others. The modifications basically vary the k-values for individual months. On closer examination, the proposed modified equation $u = k_c k_t f$, in which $f = tp/100$, can be

$$u = \frac{k_c p}{10} \frac{k_t t}{10} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

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12 Van Bavel, C. H. M., Fritschen, L. J., and Reginato, R. J., "Surface Energy Balance in Arid Lands Agriculture 1960-61," Production Research Report No. 76, U. S. Dept. of Agric., Washington, D. C., December, 1963, pp. 1-46.

13 Pruitt, W. O., "Cyclic Relations Between Evapotranspiration and Radiation," Transactions, ASAE, Vol. 7, No. 3, 1964, pp. 271-275, p. 280.

14 Stevens, J. C., and Stewart, E. H., "A comparison of Procedures for Computing Evaporation and Evapotranspiration," Publication No. 62, Internatl. Assn. of Scientific Hydrology, Internatl. Union of Geodesy and Geophysics, Berkeley, Calif., 1963.

15 Briggs, L. J., and Shantz, H. L., "Hourly Transpiration Rate on Clear Days as Determined by Cyclic Environmental Factors," Journal of Agricultural Research, Vol. 5, No. 4, Washington, D. C., January, 1916.

16 Briggs, L. J., and Shantz, H. L., "Daily Transpiration During Normal Growth Period and its Correlation With the Weather," Journal of Agricultural Research, Vol. 7, No. 4, Washington, D. C., October, 1916.

17 Lowry, R. L., Jr., and Johnson, A. F., "Consumptive Use of Water for Agriculture," Transactions, ASCE, Vol. 107, 1942, pp. 1243-1302.

18 Olivier, H., "Irrigation and Climate," Edward Arnold, Ltd., London, England, 1961, 250 pp.

19 Turc, L., "Estimation of Irrigation-Water Requirements, Potential Evapotranspiration: A Simple Climatic Formula Evolved Up to Date," Annals of Agronomy, Vol. 12, 1961, pp. 13-49.

20 Thompson, C. B., "Irrigation Water Requirements in Texas," Journal of the Irrigation and Drainage Division, ASCE, Vol. 90, No. IR3, Proc. Paper 4040, September, 1964, pp. 17-40.

and because k_t was given as equal to $(0.0173t - 0.314)$, Eq. 1 can be written

$$u = \frac{k_c p}{10} \; \frac{(0.0173t^2 - 0.314t)}{10} \; \ldots\ldots\ldots\ldots \quad (2)$$

indicating a nonlinear relationship of estimated u with mean air temperature, t, and a constant for a given month and location, $k_c p/10$.

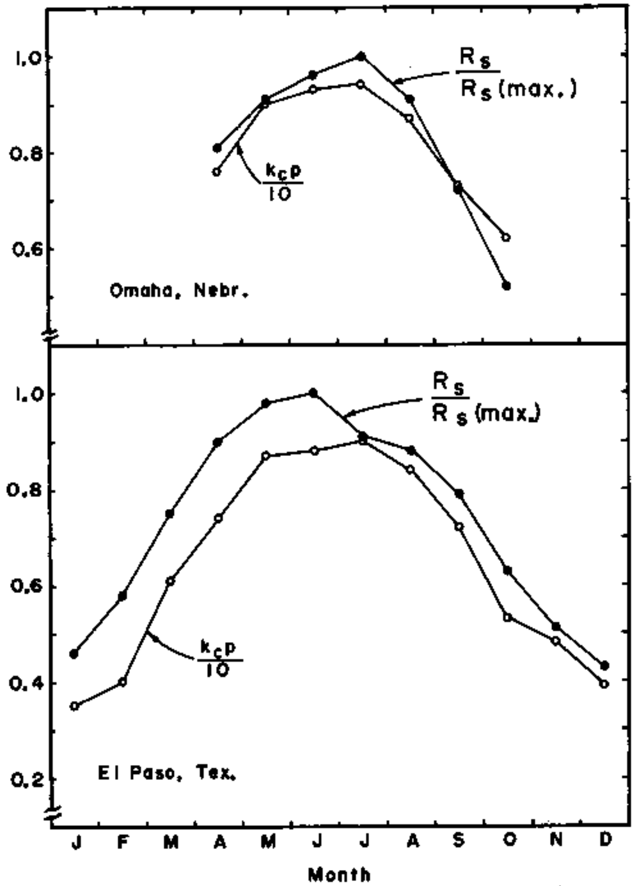

FIG. 4.—COMPARISON OF k_c p PER 10 WITH SOLAR RADIATION R_c PER R_s (MAX.)

A crop such as lawn grass should not exhibit stage of growth characteristics for individual months if no dormant periods occur. The values of k_c probably represent an adjustment for the variation in solar radiation rather than variations in crop characteristics as proposed, especially when combined with p/10 (see Fig. 4). The values $k_c p/10$ for Omaha, Nebr., and El Paso, Tex., illustrate the close association of $k_c p/10$ with solar radiation (Fig. 4).

The modifications of the Blaney-Criddle formula necessary to improve its reliability for monthly estimates thus appear to be a diverse, indirect adjustment for variation in average radiation during the season. Modifications such as those proposed by Quackenbush and Phelan actually make the Blaney-Criddle formula more cumbersome to use than equations that involve the direct use of solar radiation that is the major component of net radiation. Also, equations that use solar radiation directly can be used for estimates in individual years. One example of a simple, direct empirical equation for estimating potential evapotranspiration presented by Marvin E. Jensen and Howard R. Haise[21] is summarized as

$$E_{tp} = (0.014t - 0.37)\ R_s \quad \ldots\ldots\ldots\ldots\ (3a)$$

in which t = the mean air temperature in °F,

or

$$E_{tp} = (0.025t + 0.08)\ R_s \quad \ldots\ldots\ldots\ldots\ (3b)$$

in which t = mean air temperature in °C and R_s = the evaporation equivalent of solar radiation. A comparison of the potential evapotranspiration equation

TABLE 5.—CORRELATION OF MONTHLY SOLAR RADIATION AT LOCATION (A) WITH LOCATION (B)

Location A	Location B	Distance between, in miles	a[1]	b[1]	n[2]	r[3]
Bismarck, N. Dak.	Glasgow, Mont.	295	0.44	0.924	53	0.984
Grand Junction, Colo.	Ely, Nev.	340	-.44	1.011	75	.979
Great Falls, Mont.	Spokane, Wash.	290	1.22	.830	61	.979
Medford, Ore.	Boise, Ida.	340	-.76	1.073	98	.990
Midland, Tex.	Dodge City, Kan.	430	1.76	.842	66	.945
Rapid City So. Dak.	Bismarck, N. Dak.	220	1.36	.897	107	.977

[1] Values of the constants in the linear correlation equation A = a + bB.
[2] n = number of observations.
[3] Correlation coefficient.

presented by Jensen and Haise with lysimeter data in California indicated that evapotranspiration by clipped grass averages approximately 0.9 E_{tp}. Both solar radiation and mean air temperature are considered in Eq. 3a, and both are involved for individual year estimates.

[21] Jensen, Marvin E., and Haise, Howard R., "Estimating Evapotranspiration From Solar Radiation," Journal of the Irrigation and Drainage Division, ASCE, Vol. 89, No. IR4, Proc. Paper 3747, December, 1963, pp. 15-41.

The United States Weather Bureau (USWB) reports mean monthly solar radiation for approximately 80 locations throughout the United States in the National Summary of Climatological Data. In addition, mean daily solar radiation for the United States, by months and for the year, have been summarized by the USWB.[22] The radiation data, expressed in langleys, are presented in both graphical and numerical form on this sheet. A langley denotes 1 gm cal. per sq. cm. Conversion factors, assuming a constant heat of vaporization of 585 cal. per gm of water, are

$$\frac{\text{Langleys}}{1486} = \text{in. evaporation equivalent.}$$

$$\frac{\text{Langleys}}{58.5} = \text{mm evaporation equivalent.}$$

Jensen and Haise[21] presented weekly mean daily values of solar radiation and mean monthly solar radiation for twenty locations in the western United States. These solar radiation values were expressed as inches per day evaporation equivalent for weekly means and as inches for the monthly values. Several states are now publishing detailed information on solar energy throughout the state. An example of a recent publication of this type is presented by N. J. Rosenberg.[23] S. Fritz and T. H. McDonald[24] presented techniques for estimating average solar radiation in the United States based on observed percentage of sunshine.

One apparent reason why solar radiation has not been used extensively by water engineers is the reluctance to interpolate between observation stations. An example of the close relationship between radiation measured at two locations approximately 300 miles apart is presented in Fig. 5. Similar correlations are presented for several other locations in the western United States in Table 5 to illustrate that for individual summer values, interpolations having a coefficient of variability of approximately 7% can be made between stations up to four hundred miles apart. For long-time average values, interpolations would be within 1% to 3% for western areas. Estimates of mean monthly values during a given year for other locations can be obtained in a similar manner using a linear relationship obtained by plotting the mean values for the location in question (A) against a nearby observation station (B). These mean values can also be obtained from the National Atlas.[22] Thus, the present network of radiation stations throughout the United States provides adequate mean monthly values of solar radiation for estimating consumptive use.

This analysis was prepared primarily to encourage engineers in the water field to consider using improved estimating procedures that use either net radiation or solar radiation directly instead of indirect and less accurate adjustments. In many instances the procedures are as simple, and often easier to use, than methods such as the modified Blaney-Criddle formula that attempt to correct for variation in solar radiation by indirect techniques. Within the next 10 yr even greater improvements in estimating techniques are anticipated

22 "National Atlas of the United States," Superintendent of Documents, U. S. Govt. Printing Office, Washington, D. C., 1964 (available as separate sheet for 25¢).

23 Rosenberg, N. J., "Solar Energy and Sunshine in Nebraska," Research Bulletin 213, Nebr. Agric. Experiment Sta., Lincoln, Nebr., January, 1964, 31 pp.

24 Fritz, S., and McDonald, T. H., "Average Solar Radiation in the United States," Heating and Ventilating, July, 1949.

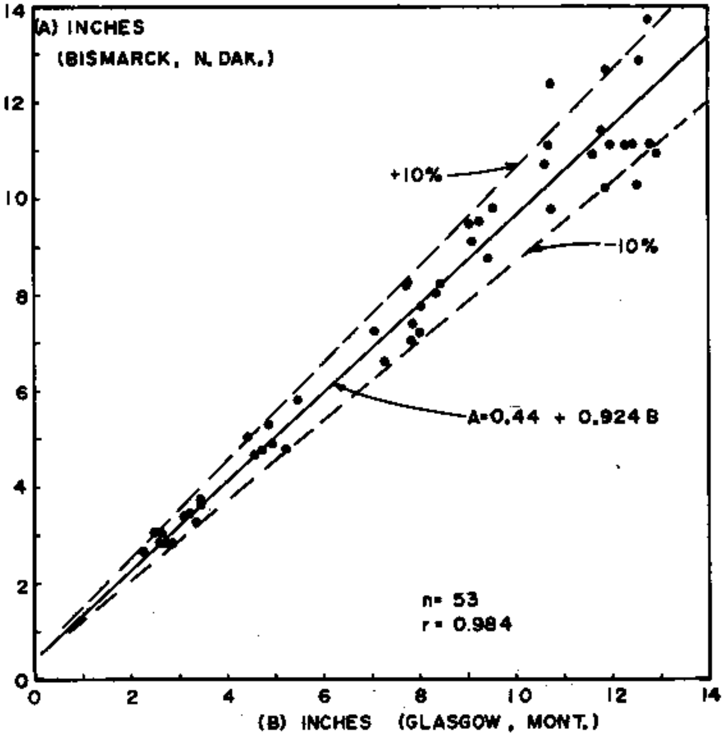

FIG. 5.—COMPARISON OF INDIVIDUAL MONTHLY VALUES OF SOLAR RADIATION AT TWO LOCATIONS APPROXIMATELY 300 MILES APART

that will permit engineers to estimate consumptive use for most crops and for varying degrees of vegetative cover. Solar radiation or net radiation will, in all probability, be a major parameter in these equations.